LA-UR-18-27493

Title:	Fiber Optic Point Sensors for ESD Data Experiments
Author(s):	Snyder, Hans R.
Intended for:	NSR&D Proposal for submission to NA-50
Issued:	2018-08-07

Fiber Optic Point Sensors for ESD Data Experiments

Abstract:

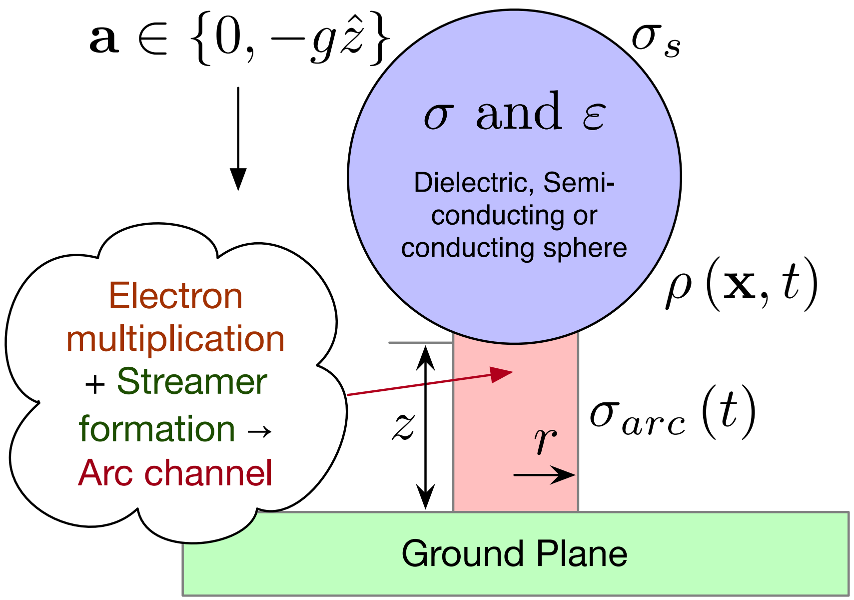
This NNSA NSR&D project will create an experimental data base of direct fiber optic point measurements of $E(\mathbf{x},t)$ and $B(\mathbf{x},t)$ from a ESD event. The data will be used to validate a physics based toolset being developed at LANL. The measurements can also be used to ascertain if a specific type of ESD event exceeds the NO FIRE limits for detonators.

Hans Snyder, NEN-2

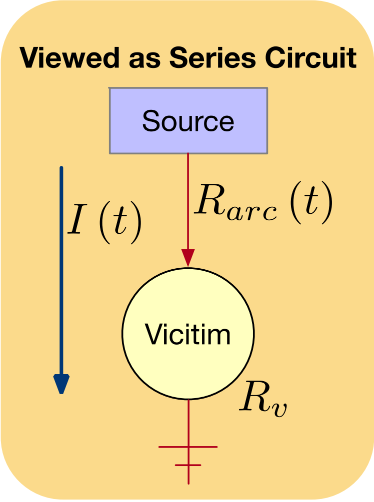
August 8, 2018

Simple Representative ESD Scenario

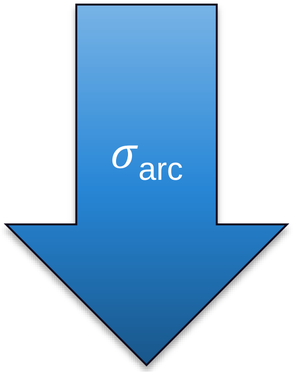
Maxwell's Equation Solver (MES) + Plasma Kinetic Arc Breakdown Solver



- **Geometry: sphere above ground plane**
  - A sphere, characterized by conductivity σ and permittivity ε, is positioned at a fixed height z or dropped from a representative height above a ground plane.
  - 20 kV/cm ≤ V ≤ 30 kV/cm → Q
  - The MES provides the initial condition: $\rho(\mathbf{x},t_0) \rightarrow \rho(\mathbf{x},t)$
    - Generally yields $\mathbf{E}(\mathbf{x},t)$, $\mathbf{B}(\mathbf{x},t)$, $\rho(\mathbf{x},t)$ and $\mathbf{J}(\mathbf{x},t)$
    - These field quantities are required to simulate the arc formation, and the discharge from the sphere, through the arc, and into the victim load and ground plane.



Threshold Arc: $R_{arc}(t) \gg 1\ \Omega$



Overdriven Arc: $R_{arc}(t) \ll 1\ \Omega$

- **Discharge Arc: $R_{arc}(t)$ is the required unknown**
  - **High resistance** →Initial avalanche (streamer)
  - **Discharge path formation:** $\sigma_{arc}(t)$ strongly depends on % ionization
  - **Basic plasma effects:**
    - **Energy:** field heating, inter-species transfer, conduction
    - **Particles:** ionization, recombination, attachment, diffusion
    - **Flow:** channel expansion, shockwave propagation
  - **Relaxation:** recombination + cooling → **High resistance**

Project Outline

Problem and Solution:

The ESD Issue: Because costly and unrealistic conservative assumptions about ESD events drive mitigations for safety operations, the fundamental scientific work of creating and implementing a credible physics-based toolset to address ESD scenarios does not exist.

Solution Product: Create an experimentally validated physics-based toolset that can be utilized to simulate ESD discharge events in air, and thus support a defensible position to implement a less conservative NES weapon response.

Strategy:

- Use First principles approach to solve the problem
- Use simple and straight forward representative ESD scenario
- Use base models + toolset + data set
- Use asymptotic Non-Linear Resistance models
- Use data to support non-linear modeling
- Use toolset and database to support position in NES weapon response.

Fiber Optic Point Sensors for Generating Validation Datasets

Experiment Basics and Plan

- LANL currently has plasma science efforts to develop fiber optic sensors to measure magnetic field and electric field with high spatial resolution and temporal resolution
- Magnetic field measurement based on the Faraday Effect
- Electric field measurement based on the Kerr Effect and Pockel Effect
- Diagnostic can be used to measure electric field and magnetic field for various ESD experiments
- Experiment data can be used to validate physics based toolset
- Experiment data can also be used to ascertain if an ESD event, *under realistic conditions*, coulde transfer energy in such a way that exceeds the NO FIRE limits for a given detonator.

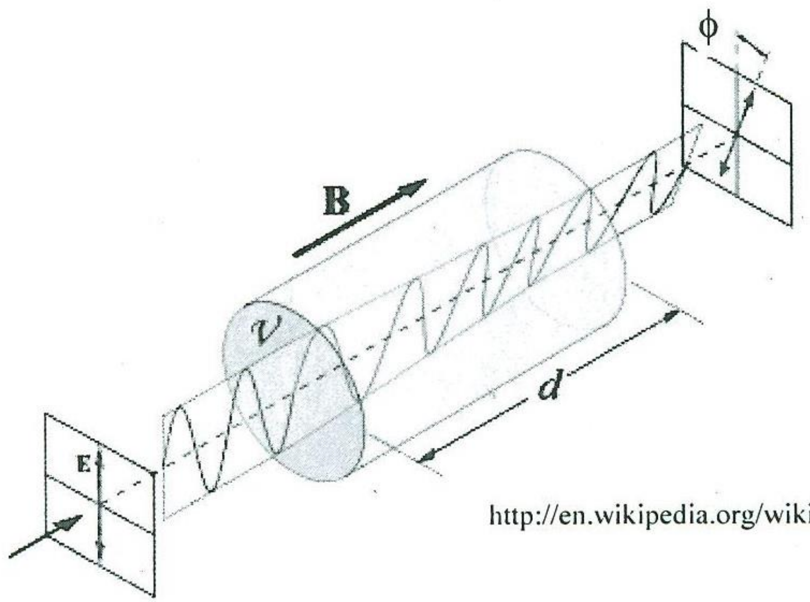
Fiber Optic Point Sensors for Generating Validation Datasets

Experiment Basics and Plan

- **LANL currently has plasma science efforts to develop fiber optic sensors to measure magnetic field and electric field with high spatial resolution and temporal resolution**
- **Magnetic field measurement based on the Faraday Effect**
- **Electric field measurement based on the Kerr Effect and Pockels Effect**
- **Diagnostic can be used to measure electric field and magnetic field for various ESD experiments**
- **Experiment data can be used to validate physics based toolset**
- **Experiment data can also be used to ascertain if an ESD event, *under realistic conditions*, can transfer energy in such a way that exceeds the NO FIRE limits for a given detonator.**

Fiber Magneto-Optic Sensor

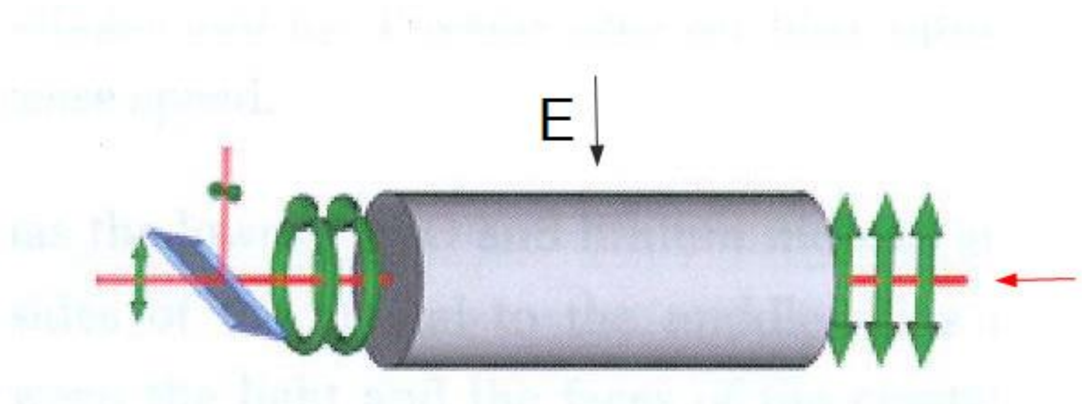
- Magnetic Field Optical Fiber Measurement Based on Faraday Rotation
- Degree of rotation Ø of the plane of polarization is dependent on the strength of the magnetic field
- Sensitivity of diagnostic is dependent on the wavelength of the light and material properties of the fiber



http://en.wikipedia.org/wiki/Faraday_effect

Fiber Electro-Optic Sensor

- Pockels Effect is a linear electro-optic changes that creates birefringence in a optical material from a applied electric field. Birefringence is the an optical phenomena where the refractive index depends on the polarization of light.
- Kerr Effect is a quadratic electro-optic effect.
- Change in polarization vector depends on the strength of the electric field
- Sensitivity of diagnostic depends on material properties of the fiber



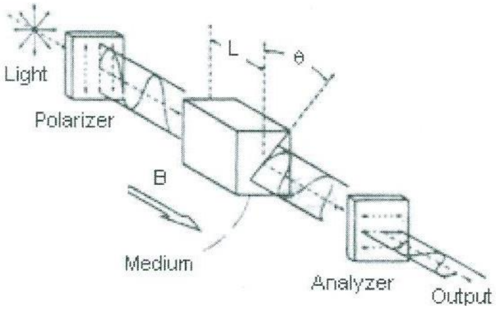
https://en.wikipedia.org/wiki/Pockels_effect

Fiber Sensor Experiment Tasks

- **Determine most effective materials for magneto-optic and electro- optic sensor**
- **Custom fabricate fiber cable using selected materials for each type of sensor**
- **Determine if sensitivity of sensor is sufficient to generate relevant data**
- **Determine if sensor can be configured in a manner to be of practical use for ESD application.**
- **Compare experimental data to toolset calculations**

Basic Test Steps

- Test various size metallic spheres
- Charge sphere to various voltage
- Initiate ESD event
- Measure electric field and magnetic field at a point of interest
- Calculate total energy transfer over ESD event



Basic Experimental Test Set-Up